Exxon Valdez Oil Spill
Restoration Project Final Report

Forage Fish Diet Overlap, 1994-1996

Restoration Project 98163C
Final Report

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Study History: "Forage fishes are abundant, schooling fishes preyed upon by many species of seabirds, marine mammals, and other fish species. They provide important ecosystem functions by transferring energy from primary or secondary producers to higher trophic levels," (Springer and Speckman, 1997). A number of these planktivorous species inhabit Prince William Sound (PWS), some supporting important commercial fisheries and all contributing to food webs leading to apex predators. The population dynamics of these forage resources can thus influence the health of their predator populations. Forage fish studies in PWS grew out of observations that seabird populations have failed to recover several years after the acute, massive damage caused by the oil spill, and that their trophic resources have shifted between the late 1970's and the 1990's (Piatt and Anderson, 1996; Oakley and Kuletz, 1996; Bechtol, 1997; Anderson et al, 1999). Researchers felt that an ecosystem study was needed to understand the linkages between these observations.

The initial investigation began in 1994 as Forage Fish Influence on Recovery of Injured Species: Forage Fish Diet Overlap (Sound Ecosystem Assessment (SEA) Restoration Project 94163; Willette et al, 1995). This project was designed to assess the abundance, species composition, distribution and diet overlap of forage fish species within PWS to increase understanding of recent declines in their predators (Springer, 1992; Anderson et. al, 1997; Bechtol, 1997). It was conducted by Alaska Department of Fish and Game (Cordova) concomitantly with two other SEA projects, Salmon Predation (94320E) and Salmon Growth and Mortality (94320A). The National Marine Fisheries Service, Auke Bay Laboratory (NMFS-ABL) and the University of Alaska, Fairbanks, Institute of Marine Science (UAF-IMS) were contracted to process forage fish stomach and prey samples collected by SEA in 1994. In August and November of 1994, the forage fish project was replaced by a multi-agency pilot project that jointly examined seabirds and forage fish. This second project evolved into the Alaska Predator Ecosystem Project (APEX). APEX focuses on the trophic interactions of seabirds and the forage species they depend on. The interconnected components of the five-year study are designed to examine fish ecology, seabird foraging at sea, and seabird reproductive success and colony dynamics on land (Duffy, 1998). In the two years that fish diet overlap studies were part of APEX, the fish population segment of the project (163A) was headed by the University of Alaska, Juneau Center for Fisheries and Ocean Science (JCFOS), and ABL assumed responsibility for the diet overlap sub-project.

Abstract: The Forage Fish Diet Overlap component of the Alaska Predator Ecosystem Experiment (APEX) investigated the trophic interactions of forage fish prey of seabird populations which were impacted during the *Exxon Valdez* oil spill. We analyzed more than 5000 specimens of 14 forage species, and zooplankton and epibenthic prey samples from Prince William Sound (PWS), 1994-96. Forage fish were collected monthly in western PWS with purse seines in 1994 and in three regions of PWS (southwestern, central and northeastern) with a mid-water trawl in 1995 (summer and autumn) and with a beach seine in 1996 (summer). The species examined were mainly young-of-the-year (YOY) and age-1 walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea pallasi*), Pacific sandlance (*Ammodytes hexapterus*), pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), Pacific cod (*Gadus macrocephalus*), Pacific tomcod (*Microgadus proximus*), prowfish (*Zaprora silenus*), northern smoothtongue (*Leuroglossus schmidti*), eulachon (*Thaleichthys pacificus*),

capelin (*Mallotus villosus*), threespine stickleback (*Gasterosteus aculeatus*), and Pacific sandfish (*Trichodon trichodon*). We compared seasonal size, diet composition and diet overlap between species from May-November, 1994; described the diets, prey fields and prey selection of juvenile pollock and herring in summer and autumn, 1995 and of juvenile herring, sandlance and pink salmon in summer, 1996; examined for prey shifts and feeding declines when the 1995-96 fish occurred in multi-species aggregations (sympatrically) compared to when they occurred in single species aggregations (allopatrically) to test for competition; and compared diet composition interannually for several species in July of the three years.

Most forage fish species were planktivorous during the six months sampled in 1994, with large and small calanoid copepods a consistent component of prey biomass. Small calanoids were predominantly *Pseudocalanus*, but a succession of large calanoids were consumed throughout the season. *Neocalanus* spp. were prominent in May and *Metridia* spp. were conspicuous in summer and autumn. Species' diets shifted to a variety of macrozooplankters in summer and autumn, but in different months. Pacific tomcod and salmonids were the least planktivorous forage species, but piscivory was occasionally observed among other species. Food webs were the most complex in June, when both significant diet overlap and prey partitioning were commonly observed. Diet overlap between species pairs shifted monthly, and herring and pollock diets overlapped the most consistently. Herring, tomcod, capelin, and pink and chum salmon diets differed each year in July, but sandlance and pollock diets were consistent between years.

Evidence for trophic competition was found from comparisons between the diets of YOY forage species in allopatric and sympatric aggregations in 1995 and 1996. Small calanoid copepods were the predominant zooplankter available in both summer and autumn, but YOY herring and pollock preferred larger prey in autumn. Summer diets of allopatric pollock and herring overlapped by 76% biomass, mainly on the basis of small calanoids. Autumn diets of sympatric pollock and herring also overlapped (mean 55-88% biomass of prey species), the common prey being large calanoids, larvaceans and euphausiids. In autumn, YOY herring and pollock consumed greater numbers of prey in allopatric aggregations than in sympatric aggregations, indicating that competitive interactions inhibited the feeding of both species during this period of declining prey abundance.

In summer, 1996, trophic interactions of three forage species were compared between allopatric and sympatric aggregations. Prey partitioning was indicated by low interspecific diet overlap between sympatric species pairs. Intraspecific comparisons showed that sandlance shifted diets in the presence of other planktivores, but pink salmon and herring diets remained similar whether they occurred allopatrically or sympatrically. Juvenile sandlance and herring consumed small calanoids and larvaceans in proportion to their availability in the zooplankton; juvenile pink salmon strongly selected larvaceans, avoided small calanoids and sometimes consumed fish. Changes in prey composition, changes in diet similarity, and feeding declines indicated that competitive trophic interactions occur among herring, pink salmon and sandlance in summer. Significant declines in food quantity and stomach fullness for all three species in sympatric aggregations were the most dramatic indication of competition, and may have been related to a trend for decreased zooplankton densities in areas of sympatric aggregations.

Our results show that food webs in PWS are complex. Although shifts in diet may compensate to some degree, competitive interactions among forage species can result in reduced feeding. If sympatry occurs regularly under conditions of limited food availability, interspecific competition could affect the carrying capacity of PWS for these species. Density dependent effects have not been thoroughly examined. However, the migration of the majority of juvenile pink salmon to the Gulf of Alaska earlier in the summer reduces their interactions with other planktivorous forage fish in PWS.

Key Words: allopatric and sympatric, competition, diet composition, diet overlap, forage fish trophic interactions, prey fields, prey selection, Prince William Sound, seasonal changes in diet.

Project Data: *Description of data* - The forage fish size and stomach contents data, zooplankton prey field data and epibenthic prey field data were generated from laboratory measurements and microscopic analysis of samples collected by the SEA and APEX projects in 1994-1996. Food habits raw data consist of counts of prey organisms with prey weights estimated from literature values and data on file. *Format* - Data generated by Auke Bay Laboratory for the sample years 1994-1996 and by the University of Alaska, Institute of Marine Science Fairbanks Laboratory for 1994 were finalized in Microsoft ACCESS databases. *Custodian* - Contact Molly Sturdevant, Fisheries Research Biologist, Auke Bay Laboratory, NWAFSC/NMFS/NOAA, 11305 Glacier Highway, Juneau, Alaska, 99801-8626 (work phone: (909) 789-6041, FAX: (907) 789-6094, EMAIL: molly.sturdevant@noaa.gov). *Availability* - Data summaries are available upon written request.

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INTRODUCTION

Seabirds are sensitive to food quality, abundance and distribution. The carrying capacity of the forage environment for pigeon guillemots (*Cepphus columba*), for example, is believed to be higher when greater populations of pelagic (high lipid) forage fish are present. Decadal-scale shifts in the Gulf of Alaska (GOA) oceanographic regime are believed to play a role in the trophic shifts documented for seabirds (Piatt and Anderson, 1996). Declines in lipid-rich capelin and other forage species and increases in lipid-poor gadids and flatfish are well-documented, but it remains uncertain whether these community shifts were caused by the major oceanographic changes in the region (Duffy, 1998; Anderson et al, 1999). Similarly, the effects of the forage fish community shift on forage fish trophic dynamics are unknown. Bottom-up and top-down controls are currently being debated (e.g., McRoy et al, 1999). The prey resources of forage fish must also respond to oceanographic changes, the densities of their own prey, and to densities and distributions of their predators and competitors (e.g.., Brodeur and Ware, 1992; Tanasichuk 1998a, b; Mohammadian et al, 1997; Frost and Bollens, 1992). If oceanographic regime shifts did cause these GOA fish community changes, we may also ask how they influenced the zooplankton food available to forage fish species, whether competitive interactions between forage species shifted as community composition changed, and whether interactions between members of the changing community of planktivorous forage species that comprise seabird prey resources could influence their foraging and reproductive success. These complicated questions cannot be answered without information about the food habits and feeding biology of the fish, as well as studies on the biology of their prey resources. The goal of the forage fish diet study was to provide basic information on forage fish trophic ecology to this end.

This final report consists of three chapters which synthesize the principal findings of three years of forage fish diet data. All of the APEX diet data has previously been reported in annual reports (APEX Projects 95163C-98163C), but SEA Project 94163 has not been completely reported on. Chapter 1 is the first presentation of this data set. Interim reports of the 1994 forage fish diet data were presented before sample processing was completed (Sturdevant, 1995) . The annual report of 94163 included only the late summer data (Willette et al, 1995; Willette et al, 1997), and other data subsets were included in the Salmon Growth and Mortality Project 94320A annual report (Willette et al, 1995). Chapter 1 describes the overall sizes, diet composition, and diet overlap of the 14 forage fish species examined over three years by the Forage Fish Diet Overlap project from monthly, pooled SEA-APEX data. The biomass summary presented here was also incorporated into the trophic mass-balance model of Alaska's PWS Ecosystem (Okey and Pauley, 1998). Chapters 2 and 3 are more in-depth drafts of manuscripts from APEX data with specific analyses that compare principal forage species in allopatric and sympatric aggregations and describe zooplankton prey fields; these manuscripts are in review prior to journal publication. Chapter 2 examines YOY herring and pollock in summer and autumn, while chapter 3 examines juvenile herring, sandlance and pink salmon in summer. In addition, the annual report of APEX Project 98163S (Purcell et al., 1999) utilizes the 1995-96 data to examine the trophic structure of PWS and the potential competition of forage fish and jellyfish by comparing diets of herring, pollock, sandlance and pink salmon to those of *Aurelia, Cyanea, Aequorea*, and *Pleurobrachia*.

OBJECTIVES

The forage fish diet component of APEX was directed under the hypothesis that "planktivory is the factor determining abundance of the preferred forage species of seabirds." The objectives of the diet study were to collect samples of forage fish for analysis of stomach contents; collect samples from prey fields (zooplankton, epibenthos) for analysis of available prey taxa; to perform laboratory analyses of stomach and prey field samples; and to describe the food habits, prey partitioning, preferred prey items, diet overlap and potential competition between forage species. Providing such information is a first step toward unraveling a trophic cascade that may contribute to lack of seabird recovery.

METHODS

The complete methods employed by SEA 94163 and APEX 163A-C and involved in producing this report appear in the annual reports and the written protocols (see Sturdevant, 1997) for each sub-project. These are briefly summarized below.

Sample collection -- In the first year of PWS forage fish studies, SEA samples were collected opportunistically in conjunction with other projects. Forage fish specimens were collected approximately monthly, between April and September, 1994 in western PWS, using multiple gear types. The samples analyzed were caught principally with two sizes of purse seines (see Chapter 1, this report; Willette et al., 1995). A stratified sampling design was employed in that year, with month and habitat type (shallow bay, moderate slope passage, steep-slope passage) as strata. In August-September, 1994, SEA sampling focused on forage fish sampling, including collection of zooplankton and epibenthic prey fields and a 24-hour diel study at a shallow bay site (Iktua Bay). The project was redirected in July and November, 1994. At these times, a mid-water trawl was used on a pilot basis to survey three geographic regions of PWS (southwestern, central and northeastern) along a parallel transect grid (Haldorson, 1995). Diet samples were collected only in the latter cruise. In summer and autumn, 1995, APEX Project 95163C used the mid-water trawl to fish on hydroacoustic targets along the same transect grid (see Haldorson, Shirley and Coyle, 1996). In summer, 1996, APEX Project 96163C surveyed the offshore area and a shoreline grid of zig-zag transect lines with two sets of hydroacoustic gear. Forage fish samples were collected principally with beach and purse seines (Haldorson, Shirley, Coyle and Thorne, 1997). A diel study of fish feeding was conducted opportunistically at two beach seine sites, with samples collected every four hours over a 24-hour period. Zooplankton prey samples were also collected at sites where fish were caught in 1995-96. No other directed sampling was conducted (see annual reports for specific methodology).

All prey and fish samples (10-15 individuals per size class and species) were preserved in the field in 10% formalin solution and returned to the laboratory for processing. If multiple size classes in the catch were obvious, we preserved each. However, it was not possible to analyze all of the extensive collections in 1994; fish were prioritized based on the quality of information expected to be gained from processing them. The few samples from April, 1994 were not examined. After 1996, although APEX forage fish population assessments continued, forage fish diet overlap studies were discontinued due to budget constraints and limitations for field sampling and laboratory processing.

Laboratory processing --Preserved fish were measured and weighed and the stomachs were excised and transferred to alcohol. Stomachs were weighed before and after removal of contents to obtain an estimate of wet weight by subtraction. Stomach fullness and condition of the contents (relative state of digestion) were ranked according to indices. Contents were teased apart under the microscope, subsampled when necessary, and organisms identified to genus or species where possible. Prey taxa were also assigned to size groups or life history stage when appropriate (see Sturdevant, 1997 for codes and descriptions of taxa). Total weights per taxon were estimated by multiplying numbers observed by individual mean weights from the literature and data on file. Diet composition of forage species was described as the percentage contribution of taxa pooled into major taxonomic groups; grand values were estimated for pooled specimens of a species or mean values were estimated for specific aggregations, depending on the analysis (see chapters). Diet overlap and prey selection were compared between species by month or between groups of allopatric and sympatric species (see chapters for measures used). The quantities and composition of food consumed by fish from allopatric and sympatric aggregations were also compared to assess for competitive interactions. A variety of ANOVA methods and chi-square tests were used for statistical analyses in chapters 2 and 3.